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F-15 Structural Life Enhancement

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Abstract

This paper summarizes the effort funded by the United States Air Force Research Laboratory at Wright Patterson Air Force Base to identify the problem structural areas on the F-15 and recommend appropriate solutions with the development of new technology. Recent modifications to the F-15 airframe structure have taken place or are under consideration to reduce honeycomb water corrosion, reduce maintenance costs, quickly produce spares, provide technology demonstration for future aircraft, and eliminating/ reducing maintenance, including NDI inspections and problem fatigue cracking issues. The recommendations in the plan address solutions that can be integrated into an overall life extension plan for fighter aircraft.

1.0 INTRODUCTION

Fatigue and corrosion damages are issues in the USAF aging fighter aircraft fleet. Periodic inspections and replacements of the damaged components have solved many of these problems, but this approach is expensive and significantly reduces aircraft availability. In addition, damage can reoccur requiring the same repair to be performed several times. Alternative structural life enhancement technologies exist which offer more efficient solutions.

The F-15 has provided a reliable and robust airframe, even though first flight was nearly thirty years ago. The material and design technology used for this airframe was based on technology available in the late sixties, where the extensive use of titanium was considered a major technological change. The addition of the F-15E into the USAF inventory in the mid-eighties incorporated the first new structural technology, BLATS, Built-up Low-cost Advanced Titanium Structure. And, while no major structural fatigue issues have surfaced in thirty years of operation, the F-15 aircraft has experienced secondary structural cracking due to buffet and sonic fatigue at various locations along with secondary structure cracking due to maneuver loading. Additionally, corrosion in secondary and some aluminum primary structure has begun to surface, creating maintenance and logistics issues. Several recent structural modifications to the F-15 have taken place, or are under consideration: reducing honeycomb water corrosion; reducing the cost of spare parts, substitutions to quickly produce spares; providing technology demonstrators for future aircraft; and eliminating/reducing maintenance, including NDI inspections and problem fatigue cracking issues. To assess the remaining airframe issues, a survey was taken and those components that could benefit from structural life enhancement technologies were identified for further study.

Paper presented at the RTO AVT Specialists' Meeting on "Life Management Techniques for Ageing Air Vehicles", held in Manchester, United Kingdom, 8-11 October 2001, and published in RTO-MP-079(II).

Included in this paper are the results of the study conducted for the United States Air Force Research Laboratory at Wright-Patterson Air Force Base, to identify the problem areas on the F-15 and determine appropriate solutions. This study provided an assessment of available structural life enhancement technologies and was focused on technologies that can be applied on existing structure. In addition to this study, recent technological upgrades to the F-15 as spares, technology demonstrators, corrosion prevention enhancements, or resolutions to fatigue areas of concern have been included.

Each of the identified problem areas were ranked to determine which enhancement techniques offer the most potential in cost savings and increased aircraft availability. The high ranking critical locations on the F-15 (that have not been recently upgraded) include:

- Inner Wing, Lower Wing Skin at Shoulder Rib and Intermediate Spar, Edge of Skin
- Fuel Cell No. 1, Lower Keel Longeron
- Vertical Tail, Main Torque Box Composite Skin
- Vertical Tail, Main Torque Box Honeycomb Assembly
- Horizontal Stabilator, Main Torque Box Honeycomb Assembly
- Horizontal Stabilator, Main Torque Box Composite Skin
- Aft Fuselage, FS 712 Bulkhead Outboard Section
- Inner Wing, Pylon Rib
- Outer Wing, Upper Torque Box Skin at Ribs and Ribs at XW 172, XW 188 and XW 206.

From the list of high-ranking locations, several enhancement techniques were recommended for additional research and development. These included: composite patches, health monitoring, and damped bonded patch. The report was completed with plans to develop, demonstrate and transition these techniques to the F-15 aircraft. The recommendations in the plan address solutions that can be integrated into an overall enhancement plan for the F-15.

2.0 F-15 STRUCTURAL PROBLEM AREAS

2.1 Critical Locations

A survey of available sources was conducted to identify problem areas on the F-15C/D and E structure. In general, the F-15 was designed and is inspected based on crack growth methodology, or the time it takes for an initial assumed flaw to grow to failure. The analysis assumes that a "rogue" flaw exists at the most critical location on a part. The size of the initial flaw assumed was dictated by what current NDI instrumentation can reliably detect. A rogue flaw can exist for any number of reasons; i.e., material voids or inclusions, mechanically made notches or scratches, etc. In addition, the F-15 has been through numerous full-scale fatigue tests and has had extensive in-service time. Data documenting damage found during test article teardowns and fleet inspections was collected. The results of this documentation has not been included in this paper for brevity, but included descriptions of the items, how the location was determined to be a candidate, what the issue is with the location, and what is the most likely enhancement technique to eliminate the concern.

2.2 Rating System for the F-15 Critical Locations

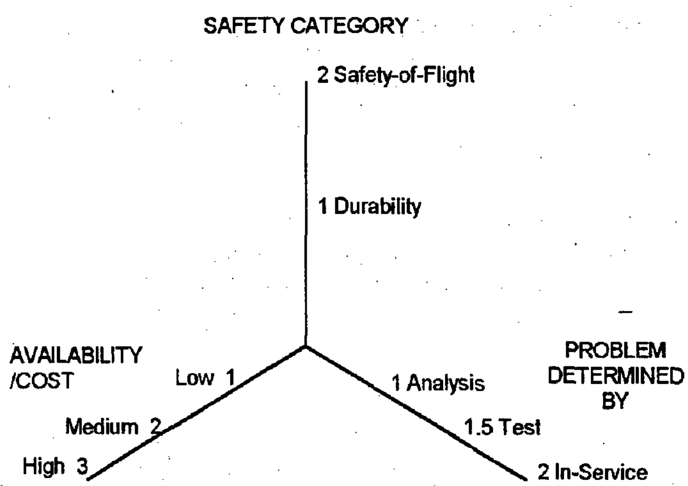
It was necessary to develop a numerical rating system for the locations found to require a maintenance or inspection action on the F-15. A three dimensional rating system was developed to weigh important aspects of each location. The three parameters used to evaluate the critical locations were safety, aircraft availability/cost of maintenance, and how the problem was determined. The product of the three parameters provides an overall rating. Figure 1 graphically illustrates the rating system.

2.2.1 Safety Category – Safety-of-flight criticality is the single most important aspect of all weighting parameters. The F-15 bases inspections on crack growth methodology, or the time it takes an initial flaw to grow to failure. For this category a rating of "1" was assigned to durability critical structure and a value of "2" was assigned to safety-of-flight critical structure. The safety-of-flight criterion, with initial flaws placed at the most critical locations and oriented in the most critical orientations, was defined to prevent failure from a rogue flaw.

2.2.2 How the Problem was Determined – All critical locations fell into one of three categories based on how the problems were determined; by analysis, by full scale fatigue testing, or by in-service failures. Analysis is the most common method of determining critical locations. This was used as the baseline and a value of one was assigned to critical locations found in this manner. Full scale fatigue testing was assigned a value of one and a half since failures found during testing or in the subsequent tear down simulate cracking that could occur in service. Loading tends to be more realistic than by analysis since loading will distribute differently than a coarse Finite Element Model might indicate. In-service failures were assigned a value of two. Failure during actual usage provides the best and clearest picture of how aircraft are used operationally.

2.2.3 Aircraft Availability/Cost – Three basic ratings (low=1, medium=2 and high=3) were assigned to all critical locations based on aircraft availability and cost. Aircraft availability refers to the impact of part maintenance on down time or mission capability and represents the effect of repeat repairs on the same component. Cost not only includes the part, but all maintenance operations. Often, replacing a "buried" part will result in a cost to the customer that far exceeds the basic part cost if major disassembly is required. Availability and cost were combined into a single parameter because of the close correlation between them. An expensive and difficult repair can lead to longer downtime. However, lower cost repairs can also cause significant downtime if parts or equipment are not available. In general, the effect of maintenance on aircraft availability is greater during field repairs.

FIGURE 1
RATING PARAMETERS FOR F-15 CRITICAL LOCATIONS



3.0 STRUCTURAL LIFE ENHANCEMENT TECHNIQUES

3.1 Life Enhancement Techniques - State of the Art

The following subsections describe the current state of the art of various enhancement techniques available. Particular aspects of these techniques are classified as "mature", "near general application", or "needs additional development". The criteria for classification are as follows.

3.1.1 Mature – Techniques under this category are in general use on operational aircraft. Procedures are well documented in Tech Order Manuals, for example. Analysis methods associated with the technology are in general use within industry. A brief listing includes:

3.1.1.1 Cold Working - Through this process, a hole is radially expanded resulting in circumferential compressive residual stresses. The compressive stresses delay crack initiation and can retard crack growth. Structural enhancements applications of parts installed on the aircraft have been improved by the development of one-sided cold working methods and rivetless nutplates [3.1]. Additional work is necessary to provide full analytical benefits from cold working.

3.1.1.2 Interference Fit Fasteners - These types of fasteners increase fatigue life by reducing the stress concentration of the fastener hole and by introducing beneficial compressive residual stresses around the hole wall. There are three types of interference fit fasteners that can be used to improve fatigue life: solid rivets, pin and collar fasteners (hi-loks and lockbolts) and tapered fasteners (taper-loks). As with cold working additional work is necessary to provide full analytical benefits from cold working.

3.1.1.3 Shot Peening – The shot peening. This process adds beneficial residual stresses for increased fatigue resistance. The material being peened must be considered in choosing shot peening intensity, shot size, shot hardness, and coverage. Shot peening is primarily used in retarding crack initiation because the depth of the residual stresses is too shallow (up to 0.03 in.) to affect crack growth. Care must be taken not to cause surface damage from over peening. High strength steel landing gears are a major application in aircraft. Recent developments in this area include the use of shot peening to search for inter-granular corrosion and exfoliation [3.2].

3.1.1.4 Fleet Monitoring - Fatigue tracking and usage monitoring programs have evolved with each new weapon system and have ranged from tracking of flight hours to multi-channel recorders and strain gages. Because of conservatism, tracking flight hours can result in premature retirement or in maintenance performed more frequently than necessary. Aircraft flown under very severe missions can exceed the design usage and accumulate damage more rapidly than expected. To improve the accuracy of aircraft tracking programs, counting accelerometers were installed in various aircraft models. These counting accelerometer-based systems can be classified as a second generation tracking system, since they follow after the simpler flight hour based method. The need for further improvements in accuracy led to the development of the third generation tracking systems based on multi-channel recorders to track additional parameters. Fourth generation systems have incorporated strain gages to more directly compute stresses in the tracked components.

It is possible to upgrade fatigue-tracking systems to obtain more accurate data. As mentioned earlier, more accuracy reduces conservatism and can result in longer inspections intervals or longer operational life. However, the cost of a fatigue tracking system upgrade can be prohibitive for some fleets. One of the reasons for the high expense is the cost of integrating a new system with the existing hardware and software. A stand-alone health monitoring system that can be installed without affecting other aircraft system offers many advantages.

3.1.2 Near general application – A technique in this classification has been used on a limited number of operational aircraft or has been applied on only specific aircraft types, but is not in general use on the USAF fleet. Process is documented, but requires engineering supervision. Analyses methods associated with the technology have been verified, but are in use by a limited segment of industry (one contractor, for example).

3.1.2.1 Corrosion Prevention - Grinding to remove damaged material or part replacements are standard methods for repairing corrosion. Coatings are needed to protect the part from subsequent corrosion with the goal of restoring the required operational life or in some cases extend the life. One of the major issues currently affecting corrosion control is the effect of non-chromated primers and conversion coats. These materials will see increased use as conventional coatings containing hexavalent chromium are replaced.

3.1.2.2 Damped Bonded Patch - Fatigue from vibratory loads is a common cause of structural failure in fighter aircraft. The F-15 lower fuselage skin has been affected by acoustic fatigue, while the outer wing upper skins have experienced buffet. Constrained viscoelastic layer damping treatments are one method to reduce vibration.

A more effective method being evaluated combines damping within a composite material patch. The patch can be bonded very effectively to the structure while containing the necessary damping. Under a company sponsored IRAD project, Boeing developed damped composite patches to reduce acoustic response on the F-15 [3.3]. These damping patches have flown on lower fuselage skins and doors of two F-15s resulting in up to a 69% reduction in vibration.

3.1.2.3 Composite Patches - Composite patch repairs of cracked metallic structure have been applied extensively by the United States Air Force Warner Robins-Air Logistics Center on the C-141 and C-130 fleet. Several patches have also been installed on B-52 and F-16 aircraft. Under United States Air Force sponsorship, Boeing is currently performing the Composite Repair of Aircraft Structures (CRAS) program. The program objectives are to: (1) fill in gaps in the existing composite repair patch technology, and (2) promote the technology with new users such as the F-15.

An application for composite patches is on the front wing spar on the F-15 aircraft. Fatigue cracks have been found in the web of this spar emanating from a conduit hole in earlier F-15 models. Bolted repairs have been developed for this problem, and the component was redesigned in the F-15E. However, inspections are still required to detect if cracks are present.

Under the CRAS program, Boeing has developed a pre-emptive patch for this location. The patch restores the required crack growth life, reduces inspections and avoids drilling of holes required for bolted repairs. Laboratory tests are in work using two machined specimens representing the F-15 spar conduit hole location. The first specimen will contain an initial crack and will be tested without a patch in order to obtain baseline data. The second specimen will also have a crack started, but this time the specimen will be repaired with a composite patch. Both specimens will be fatigue tested to failure to verify the life improvement expected with the composite patch. Conventional strain gages will be used in both tests. A demonstration of the patch on an operational F-15 is also planned.

Once these tests are completed the technology will be ready for additional applications on the F-15. One area where additional development is needed is in health monitoring systems that result in a "smart patch" capable of detecting disbonds. Such a system would promote applications in areas difficult to inspect.

3.1.2.4 Grid-Lock* – Grid-lock*, patent held by BF Goodrich, is on the verge of becoming a mature technology. The F-15 is in the process of eliminating all honeycomb structure in preference of Grid-lock* to eliminate the inherent corrosion issues of honeycomb. Grid-lock* utilizes a unique method of construction by precise machining of tongue-in-groove channels, adhesive bonding, and designing structure such that each joint is reacted in shear. The F-15 has completed fatigue testing of the aileron (subjected to buffet) and is in the process of testing a wing tip to validate usage in all locations.

3.1.2.5 Laser Formed Titanium – Laser formed titanium, developed by AeroMet Inc. (Eaden Prairie Minn., USA) is another process that is on the verge of becoming a mature technology. The F-15 is in the process of manufacturing spares developed from laser formed titanium to lower overall part cost and reduce overall cycle time. Laser formed titanium is developed by depositing a layer of pre-alloyed titanium powder on a target plate with a CO2 laser. From this target plate flanges, stiffeners, etc. are built up. Final machining can eliminate this target plate if the target plate properties are not desired.

* Grid-lock is a registered trademark

3.1.2.6 Material Substitution – The F-15 is currently under consideration to replace aluminum parts that are found corroded with the newly developed aluminum 7055, produced by Alcoa. Lower longerons and skins under the fuel cells and the flap hinge beams are regularly found and replaced for corrosion. Unfortunately, the replacement material used is the same as was the original design. The new material is now under investigation for verification of material properties and is hoped to replace all 7000 series parts in the future.

3.1.3 Needs additional development – Technologies in this category are still in the laboratory stage or have been demonstrated on aircraft as part of an R&D project. This category may also include more established methods where technology gaps exist. Analysis methods may exist, but need verification.

3.1.3.1 - Advanced Riveting Technology - Force controlled riveting can result in longer fatigue life than with conventional displacement controlled riveting. The benefit is caused by greater compressive residual stresses surrounding the hole. The residual stresses lead to crack growth retardation at the riveted hole [3.4].

3.1.3.3 Active Vibration Suppression - Buffet is a major source of fatigue damage on fighter aircraft empennage structure. Two methods used in developing a solution to this problem include "smart" materials and active rudder control.

"Smart" materials distributed over vertical tail structure have been demonstrated to control structural vibration modes [3.5 – 3.9]. The results from these programs show that piezoelectric driven skins can reduce buffet loads at all flight conditions. However, power requirements and durability have limited piezoelectric system applications.

The RANN Corporation evaluated the use of active rudder control to mitigate buffet response on the F-15 and F/A-18 [3.5]. Boeing completed a wind tunnel experiment using a 15% scaled F/A-18 model to demonstrate the use of the rudder to control vertical tail buffet response [3.10]. The vertical tail was designed with a movable rudder that was controlled using a hydraulic actuator. RMS bending moment reduction of up to 42% were achieved. These reduced loads can improve the dynamic fatigue lives by factors of 4 to 10.

3.1.3.4 Laser Shock Processing - Laser shock processing, also known as laser shot peening, is a method for inducing surface beneficial residual stresses [3.11]. Energy absorbed from a laser pulse generates high shock pressure over the surface of the metal part. Energy absorption is enhanced with black paint on the metal surface. The energy is concentrated near the surface with a layer of water. Laser shock can induce residual stresses deeper than with regular shot peening (up to 0.04 in.), and it avoids surface damage. Applications of this method include high value components such as jet engine blades.

3.1.3.5 Friction Stir Welding - Friction stir welding is a process of welding by the rotation of a threaded cylindrical pin tool [3.12]. First, the rotating pin tool penetrates the material at a location where a weld is required. The material reaches the plastic state because of the frictional heat generated by the rotating tool. Finally, the rotating tool moves along the weld line, stirring the material on both sides of the weld. This results in a bond between the parts being joined. The process is in production use and new applications in complex airframe structure are in development [3.13]. One potential Service Life Enhancement application is in repair of cracked structure.

3.1.3.6 Health Monitoring – Two areas of health monitoring are the active detection of cracking and the active detection of corrosion.

For example, during a F-15 full-scale fatigue test, a strain gage was located on a wing spar cap near a crack location. Changes in strain values recorded during the test were correlated to the growth of the crack. Other methods use acoustic emissions for monitoring cracks and smart fasteners for detecting damage in bolted joints.

Corrosivity measurement is another area of health monitoring. A sensor unit has been developed by USN to record moisture and temperature [3.13]. The unit is self contained and small (4.1 cm x 4.7 cm x 1.7 cm excluding the sensor element). Data is downloaded remotely with a hand held data-gathering unit at a range of 40 m. These types of corrosivity sensors just measure the environment, but not actual corrosion.

Composite patches are an effective method of repairing cracked or corroded structure, but the patches are only good as long as they remain bonded to the structure. If done properly, modern surface preparation techniques result in very strong bonds. However, patches installed in substructure cannot be easily inspected for disbonds. Repaired primary structure must be capable of carrying limit load in the event that the patch falls off.

To address these issues, health monitoring systems that result in a "smart patch" capable of detecting disbonds are in development. One project uses strain gages and piezoelectric sensors installed on the patch to monitor the ratio of patch strain to component strain [3.14].

The damage dosimeter is an example of a stand-alone system for measuring the environment at a specific location. The dosimeter was designed to record time, temperature and dynamic data from three strain gages. It is compact (7.5 in. x 4.5 in. x 1.25 in. plus a battery pack), and does not require aircraft power or cooling. A dosimeter can be installed easily in an aircraft to record data in areas affected by dynamic fatigue caused by high acoustics or buffet, for example. Data can be downloaded from the aircraft by connecting a laptop computer to the dosimeter. Once the needed data is obtained, the dosimeter is removed.

3.2 Enhancement Techniques - F-15 Usage

3.2.1 Fastener Holes - The basic choice for critical fastener holes, if no previous enhancement had been incorporated, was to use interference fit fasteners or cold working. These improvements are mature and have shown definite improvements over standard holes. Installation of either procedure is straightforward and the both processes are well documented. Analysis of either enhancement is conservative and development of more sophisticated analytical tools can provide for increased inspection intervals.

3.2.2 Composites - Composite patches were chosen in several situations with different goals in mind. For locations where buffet, noise, or vibrations are problems, "Active Vibration Suppression" techniques or "Damped Bonded Patch" techniques are appropriate. In many cases some form of these techniques have been applied with varying amounts of success. In many early applications the suppressants have disbonded and been of limited use. Application of more robust bonding is required to build confidence throughout the fleet. For locations with high stresses, a composite patch to reduce localized stress peaks is desired. Currently, use of bonded patches is limited in nature and has not been used as an active fighter technique to eliminate "hot" spots due to unknowns associated with bonded patches. The need for this confidence is necessary as bolted repairs can create as many problems as they solve with the addition of fastener holes. "Smart" patches may be one method of obtaining confidence in bonded patches. The USAF and industry are making major break throughs in this area and practical application of bonded patches in key locations is needed to spread this technology.

3.2.3 Peening - Shot Peening and Laser Shock Processing were mentioned in a very limited fashion for critical locations. Since the F-15 inspection system is based on rogue flaw theory, these two methods have limited practical influence, as the improvements are so surface localized. In practicality either techniques would improve the economic life of the aircraft. Rogue flaws generally do not exist and cracking initiates, in almost all cases, on the surface of the part. A layer of beneficial residual stresses would retard the initial crack growth in the part.

3.2.4 Health Monitoring - Health monitoring was listed fairly extensively in the Wright Patterson study. Corrosion determination is interdependent with moisture collection. Therefore, a specific schedule cannot be defined since it is impossible to know when moisture will be trapped. With the use of a system to detect trapped moisture, corrosion can be prevented by a maintenance action to remove the accumulated water (for example, cleaning of plugged drain holes). The second health monitoring system needed is the full development of instrumentation to detect disbonds in composite structure or detection of cracks growing in areas of high stresses. As mentioned earlier, these systems exist but have not been implemented to any degree.

3.2.5 Spare and Replacement Parts –

3.2.5.1 Material Substitution - For corrosion, material substitution appears to be the optimum choice. For the F-15 lower longerons and skins, the use of 7055 may potentially provide enhanced corrosion protection. For the F-15 wing pylon, a material substitution from aluminum to titanium not only eliminates corrosion, but also eliminates issues of fatigue cracking and static overloads. Simple coatings have not offered substantial and sufficient protection from corrosion since they can be worn off or scraped away during normal operation and maintenance.

3.2.5.2 Laser Formed titanium - Laser formed titanium offers availability of titanium spare/replacement parts in a much more rapid procurement fashion. Lead times to obtain forgings can be cut in half with a significant control on costs.

3.2.5.3 Grid-Lock* - Grid-lock* helps to eliminate the water entrapment and subsequent corrosion problems seen in honeycomb structure. Use of corrosion resistant materials, i.e., 7055 aluminum, could be used to enhance these benefits. Honeycomb is extremely efficient, but not at the cost of the current maintenance burden.

4.0 SLE TECHNOLOGY DEVELOPMENT, DEMONSTRATION AND TRANSITION

For each "Near General Application" and "Needs Additional Development" technology, development steps to fill technology gaps are recommended. These are followed by demonstration plans to ensure the technology is ready for transition into the fleet. In most cases, a demonstration program should scale up the test specimens to represent actual aircraft structure.

The demonstrations should include flight tests with the corresponding aircraft to increase the maturity level and confidence in the new methods.

The following subsections describe a strategy for defining, developing, and demonstrating each enhancement technology and transitioning theses technologies to the USAF fleet.

4.1 Composite Patches

Additional work should focus on expanding technologies developed under CRAS and related programs. Specific areas include thick structure, complex geometry, repair of stress corrosion cracking and pre-emptive patches. Pre-emptive patches, installed before cracks initiate, do not need to be as robust as patches used in repair of cracked structure. They can have fewer plies, and because less stiffness is required, alternatives to boron/epoxy can be used. Analysis of these patches is needed to determine the stresses in the un-cracked structure, and predict the number of flight hours to initiate a crack. The calculated stresses are also used to perform damage tolerance assessments with an assumed initial crack (typically 0.05 inch long). New analysis methods should be verified with coupon and element tests prior to demonstration in actual aircraft parts. The tests should also evaluate the effect of temperature on the adhesive.

Another area where additional development is needed is in health monitoring systems that result in a "smart patch" capable of detecting disbonds. Because several programs are already focusing on sensors, further work on new sensor development is not necessary. Instead, additional work is needed on the integration and demonstration of this technology.

Therefore, a demonstration program on "smart pre-emptive patches" is recommended. Laboratory specimens should be instrumented with strain gages to verify stress analyses and should represent actual structure. In addition to strain, patch temperature measurements need to be demonstrated. Patches with disbonds of various sizes will help verify the ability of the sensors to detect different levels of damage. Flight tests following the laboratory demonstrations are suggested.

4.2 Health Monitoring

In addition to the smart patch mentioned in the previous section, several high-ranking locations on the F-15 were identified as candidates for health monitoring. The main source of these problems is water entrapment. Clogged drain holes can lead to water entrapment and resulting corrosion. Freezing of water within honeycomb cells can cause disbonds between the skin and the honeycomb. Sensors that signal when water is trapped could help prevent corrosion and disbonds in the identified locations by alerting maintenance personnel.

Sensor development has been conducted in other programs, and any additional work should focus on the integration and demonstration of this technology. This work should define how to use the sensors. For example, an indication of water may signal nothing more than normal drainage and would result in a false alarm. However, water present for an extended period may be caused by an actual clogged drain hole. The demo should establish the criteria to identify real problems using specimens representing actual structural configurations. The F-15 locations for sensing when water is contained in honeycomb structures are:

Vertical Tail, Main Torque Box Composite Skin
Vertical Tail, Main Torque Box Honeycomb Assembly
Horizontal Stab, Main Torque Box Honeycomb Assembly
Horizontal Stab, Main Torque Box Composite Skin

Sensors should be installed on operational aircraft to test their capacity to detect water in real conditions. The sensors should be used to measure drainage time periods. In some cases aircraft drain holes should be plugged to simulate clogged drainage. Tests should include temperature changes to evaluate the sensors in the presence of frozen water.

4.3 Interference Fit Fasteners/Cold working

One of the main technology gaps is the lack of a robust analysis methodology that accounts for the beneficial residual stresses resulting from this technique. This is especially the case with interference fit fasteners and hole propping.

NASA Langley Research Center has been developing analysis methods in this area. In cooperation with NASA, the analysis methodology should be completed and a test program defined to verify the analysis. Vendors associated with this technology should help with test plan definition. The test plan needs to cover the following:

Baseline open hole specimens
Cold worked holes
Tight fit fasteners with no interference
Interference fit fasteners (hi-loks and lockbolts)
Tapered fasteners (taper-loks)

Sleeve-bolts
Combined cold worked hole with fasteners
Titanium and steel fasteners
Single and double lap specimens with titanium, aluminum and combined layers
Constant amplitude and spectrum loading

During fabrication of the specimens, procedures for verifying the level of interference need to be demonstrated. The vendors should help in developing these procedures. Once the analysis methods are developed and verification tests completed, companies associated with this technology should help in the evaluation of results. The demonstration program should include tests with specimens representing actual aircraft structure.

4.4 Damped Bonded Patch

Damped bonded patches have flown in lower fuselage skins of the F-15. However, additional R&D is needed in this area to cover two technology gaps.

First, up to now the structure patched has been relatively thin. Additional development is needed to treat thicker structure affected by dynamic fatigue.

The second area involves the analysis. Crack initiation analysis methods based on RMS strain vs. life data exist. These methods are adequate for the analysis of thin durability critical structure, but if thicker structure needs to be repaired, crack growth analyses need to be developed.

The recommended project shall develop analysis methods and verify these with vibration (shaker) tests. The verification test specimens should include baseline un-patched panels and repaired panels containing various levels of damage and different patch configurations. Strain gages and accelerometers mounted on the specimens are necessary to measure the level of vibration suppression obtained with the patches. The propagation of cracks should be measured until the cracks reach a significant length or until failure of the specimen occurs.

A second possible set of tests can be completed with similar panels tested in an acoustic chamber. Variations in test specimen configuration include different boundary conditions and the presence of stiffeners.

Once the analysis methods are verified a demonstration program should be undertaken with test components representing actual structure. Options include acoustic chamber tests and flight demonstration of patches.

One of the solutions for buffet on the F-15 vertical tails is the installation of graphite epoxy doublers on the boron epoxy main torque box skins. Damping material, in addition to improved bonding technology, may improve the durability of these doublers.

Another F-15 location where damping patches are needed is on the Outer Wing, Upper Torque Box Skin and Ribs at XW 172, XW 188 and XW 206. Previously used damping tape at this location has been known to fall off the structure.

Although the specific candidates mentioned have focused on the F-15, the technologies should cover additional aircraft to maximize the payoff for the USAF.

4.5 Next Generation Materials and Manufacturing

Both 7055 and laser formed titanium are on the verge of becoming production capable materials. Laboratory testing is needed in each case to verify the static ad fatigue capabilities of both. Degradation of material properties over the original chosen materials would create critical issues for spares and replacement parts. Geometrical concerns generally preclude the use of increasing thickness to compensate for material property deficiencies due to other existing mating parts. New production will be capable of compensating for specific material deficiencies if the main virtue is of new material if of primary importance.

Material testing for 7055 is currently under investigation with Wright Patterson to provide a corrosion resistant aluminum. A program to substitute various candidate parts on aircraft in operation is underway. The primary intent of this investigation is to verify form, fit, and function. The F-15 ASIP office is interested in applying this technology to eliminate recurring corrosion issues.

Once material validation for 7055 are obtained, actual part selection should be made across a wide spectrum of platforms, i.e., transports, bombers, and fighters to provide maximum exposure and experience under various loading conditions and scenarios. Upon completion of all testing, spares, replacement parts, and new production should be visited for use.

Laser formed titanium has been under investigation on the F-18 and is beginning initial verification testing on the F-15. Warner Robins is experiencing shortages in parts traditionally manufactured from forgings. Lead times and high costs are making the traditional acquisition of forgings an ineffective proposition that increases the potential for aircraft groundings. The current test plans are to verify the crack growth capabilities of a spar made from laser formed titanium and to produce spars if the properties are deemed acceptable. Use of laser formed titanium is now in work to replace aluminum pylon ribs that are experiencing corrosion and fatigue cracking.

Grid-lock* testing is more mature. A complete component test for the F-15 aileron has passed successfully. Testing of the F-15 wing tip is just now been initiated. The aileron testing was sufficient to validate manufacturing of six F-15 grid-lock* replacement spares for honeycomb on the F-15. The wing tip will require additional validation due to spectrum severity and material properties.

Upon completion of the wing tip fatigue testing, all original F-15 honeycomb parts will be cleared for substitution with grid-lock*. One concern under consideration is grid-lock weight increases over honeycomb. These are small, but flutter driven locations need to be managed carefully.

Friction stir welding has had limited testing for static and fatigue properties. This process holds promise due to low heat affected zones~~,~~ but requires special consideration if a final machining does not remove the inherent "live crack" left in the operation.

Testing to accurately quantify the static and fatigue characteristics is essential to validate this process. Repair of cracked structure is a potential benefit from this process and needs to be explored since conventional welding leaves large residuals stresses and requires careful consideration of potential contaminants in the materials.

5.0 Summary

The F-15 has become involved in a large number of state-of-the-art technologies to enhance future structural capabilities. Many of these technologies are intended for new production, but careful adaptation indicates that replacement of parts with new technology for existing aircraft is a fully viable solution to current concerns. These processes are needed, and will be investigated further, as maintenance and operational budgets grow tighter in future years.

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